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14. ABSTRACT

This article discusses a model known as the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model, which integrates quantitative information about: (1) circadian rhythms in metabolic rate; (2) cognitive performance decay rates associated with wakefulness; and (3) cognitive performance effects associated with sleep inertia to produce a model of human cognitive effectiveness. The model has been under development by the DoD for more than a decade.

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MORS Workshop: Agent-Based Models and Other Analytic Tools in Support of Stability Operations

Science Applications International Corporation (SAIC), McLean, VA

25-27 October 2005

Col **Gregory C. Reuss**, USMC, Director, USMC Operations Analysis Division, Marine Corps Combat Development Command (MCCDC) and COL **George F. Stone**, US Army, Director, US Army Battle Command, Simulation and Experimentation Directorate (BCSE, Army G-3/5/7) co-chaired the unclassified workshop entitled *Agent-Based Models and Other Analytic Tools in Support of Stability Operations* at the Science Applications International Corporation (SAIC) Conference Center, 1710 Solutions Drive, McLean, VA from 25 to 27 October 2005. Three MORS Sponsors, Mr **Walter W. Hollis**, FS, Deputy Under Secretary of the Army (Operations Research), Dr **Jacqueline R. Henningsen**, FS, Director, HQ USAF/A9, and Dr **George Akst**, Senior Analyst, Marine Corps Combat Development Command, gave plenary session remarks.

Goals of the workshop were to identify techniques and methodologies that show promise for conducting analyses in support of stability operations and to determine the capabilities that agent-based models provide for military analyses. This was achieved by bringing together DoD and non-DoD analysts working on projects related to stability operations and agent-based models. 144 analysts and decision makers participated in the workshop. This number included 10 foreign nationals (three each from the United Kingdom and Germany, and two each from Canada and the Slovak Republic) and 134 US citizens. Of the latter, 53 were new to MORS.

LTC **Scott Schutzmeister**, US Army, BCSE, facilitated the workshop as our emcee. MORS President, Col **Suzanne Beers**, USAF, and Mr **Ron Adams**, of SAIC presented welcoming remarks. Brigadier General **Thomas D. Waldhauser**, Deputy Commanding General, Marine Corps Combat Development Command, was the keynote speaker and vibrantly described stability operations from the tactical level. Dr **Barbara Stephenson**, Direc-

MORS Workshop: Homeland Security/Homeland Defense Decision Support

Johns Hopkins University/ Applied Physics Lab, Laurel, MD

15-17 November 2005

In response to a NORAD and USNORTHCOM initiative, MORS conducted a Workshop on *Homeland Security/Homeland Defense Decision Support* at the Johns Hopkins University/Applied Physics Lab (JHU/APL), Laurel, MD, 15-17 November 2005. The conference was attended by 120 people representing all services, the Combatant Commands, OSD, the Joint Staff, the Department of Homeland Security (DHS), and the Homeland Security Institute (HSI). Of those attending, 40 were attending their first MORS event. Chairs of the workshop were Mr **Tom Denesia** and Dr **Andy Loerch**.

The focus of this workshop was identifying and understanding common areas for analytic support to decision makers in both the Homeland Security and Homeland Defense analytic communities. The intended audience was analysts and operational planners at all levels of the Department of Defense (DoD) and the DHS. This workshop was the first major step in establishing a relationship between these analytic communities. The goals and objectives were to identify key analytic issues and capabilities and to promote collaboration for addressing options and solutions.

Specific Objectives

- Examine critical analytic issues for protection of the homeland and identify capabilities to address these issues to support the decision makers.

- Examine specific opportunities for collaborative analyses and identify techniques to facilitate the collaboration.

- Examine tools/techniques/data sources that currently exist and ones that should be created to support decision makers.

- Examine shortfalls and gaps where analytic support could be applied to assist decision makers.

Owning the Night

James C. Miller, Ph.D., CPE, Human Effectiveness Directorate, Air Force Research Laboratory, jcmiller@brooks.af.mil

Introduction

"You must not needlessly fatigue the troops." Napoleon Bonaparte, 1796.

Night work is a crime against human biology. We cannot see well in the dark. Our metabolism slows after midnight until it reaches a nadir, usually during the pre-dawn hours. During the night, the pineal gland at the base of the brain releases the hormone melatonin which, in turn, makes us feel drowsy. At night, the likelihood that we will sleep is very high, as our brains and bodies are designed to sleep at night and to work during the day. Thus, when an operation requires staffing 24 hours per day, 7 days per week (24/7), sleep quality and quantity suffers, and sleepiness and fatigue will plague any human-machine system.

In human-machine systems, the most unpredictable component in the system is the human. After training and currency, the greatest contributor to variability in human performance is fatigue. Good human-machine system design exploits human strengths and protects the system from human weaknesses, and this is a fundamental concept in human factors engineering. The human brings to a system much more powerful pattern recognition capabilities and decision making skills than can be provided in software. However, the human also brings much more performance variability to a system than one finds in software.

Incomplete training and lack of currency are sources of human variability. When novices are learning to operate a complex system, they generally follow a learning curve. Initially, their performance is quite poor (and variable), but they learn the basics quickly. Later, their performance is better on average, but still more variable than desired. Finally, as they approach the expert level, their average performance is quite good, and exhibits small variance. Similarly, when an expert becomes rusty in the operation of a complex system, his performance may be more variable than desired until he returns to the expert level.

One of the primary hallmarks of human fatigue is increased performance variability. This is due to large amplitude, moment-to-moment fluctuations in attentiveness associated with fatigue. Average performance may be acceptable, but there are brief periods when responses are extraordinarily delayed or absent (often called "distractibility"). One is more easily distracted when fatigued.

The Air Force Safety Center sorts the generators of fatigue into five categories: physical, circadian, acute, cumulative and chronic.

1. **Physical Effects.** These effects are due to either aerobic or anaerobic overexertion.
2. **Circadian Effects.** There are inherent, unavoidable, 24-hour rhythms in human cognitive and physical performance. Most of these circadian rhythms oscillate between their high point late in the day to their low point in the pre-dawn hours with a peak-to-trough amplitude of about 5 to 10% of their average.
3. **Acute Fatigue.** Acute fatigue builds up unavoidably within in one waking and duty period. One good-quality, nocturnal sleep period cures acute fatigue.
4. **Cumulative Fatigue.** Cumulative fatigue builds up across major waking and duty periods because there is inadequate sleep between the duty periods. Recovery from cumulative fatigue cannot be accomplished with a single quality, nocturnal sleep period.
5. **Chronic Fatigue.** Chronic fatigue may set in after one to two weeks of cumulative fatigue. Its symptoms are similar to those of Chronic Fatigue Syndrome (CFS). Unlike CFS, however, the cause is continuing cumulative fatigue, and it occurs much sooner than the 6-month diagnostic requirement for CFS. The Air Force Safety Center has in the past called chronic fatigue "motivational exhaustion." While this label accounts for only one of several possible symptoms of chronic fatigue (apathy), it effectively describes the attitude that one observes in a person with chronic fatigue.

Fatigue is ubiquitous, pervasive and insidious. By ubiquitous we mean that fatigue affects everybody. There are individual differences, a few people are truly more resistant to fatigue effects than others. Unfortunately, most people seem to feel that they are more resistant to fatigue effects than others. This misperception can lead to the formation of ill-advised intentions and decisions.

By pervasive, we mean that fatigue affects everything we do, physically and cognitively. Again, there are individual differences. In the physical domain, there are those who are inherently able to train too much greater levels of strength and endurance than most. There are also inherent differences in fatigue resistance.

By insidious, we mean that when we are fatigued, we are often unaware of how badly we are performing. Most people have experienced the attention lapse associated with mild fatigue when they miss a freeway exit or realize suddenly that they don't remember the last mile or two driven on the highway.

A Fatigue Model

Fortunately, the biological changes and rhythms that cause fatigue-induced variability in human performance are relatively predictable. We have quantitative models and simulations that allow us to estimate and predict the timing and severity of fatigue episodes, given some information or data-based assumptions about when and how much people sleep. A quantitative approach was applied here through the use of the DoD's Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model. SAFTE integrates quantitative information about: 1) circadian rhythms in metabolic rate; 2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness; and, 3) cognitive performance effects associated with sleep inertia to produce a model of human cognitive effectiveness. SAFTE has been under development by the DoD for more than a decade, and the Federal Railroad and Aviation Administrations have now joined the development team.

The general architecture of the SAFTE model is shown in Figure 1. A circadian

process influences both cognitive effectiveness and sleep regulation. Sleep regulation is dependent upon hours of sleep, hours of wakefulness, current sleep debt, the circadian process and sleep fragmentation (awakenings during a sleep period). Cognitive effectiveness is dependent upon the current balance of the sleep regulation process, the circadian process, and sleep inertia. SAFTE has been validated against data that were not used in model development.[1,2,3,4]

The Fatigue Avoidance Scheduling Tool (*FAST™*) is software that is based upon the SAFTE applied model. *FAST™*, an Air Force Small Business Innovation Research product, allows planners and schedulers to estimate the average effects of various schedules on human cognitive performance effectiveness. *FAST™* was used to support six quantitative assessments that are described briefly in the remainder of this article.

1. A Fatigue Checkcard for Mishap Investigations.[5]
Investigators of workplace and transportation accidents and incidents seldom have the instruments or expertise required to determine whether or not human fatigue might have contributed to the mishap. The Fatigue Checkcard and associated protocol were designed as a screening tool to fill this need. Using the Checkcard, the investigator may generate a SAFTE-based score for seven simple observations: 1) Length of prior wakefulness; 2) amount of prior sleep for the preceding 72 hours; 3) time of mishap; 4) number of night shifts in preceding 30 days; 5) time zone change and days in zone; 6) types of human errors associated with mishap; and, 7) estimated physical exertion across the work period of interest. If the score is above a criterion level shown on the card, then the investigator should contact a fatigue expert for additional help with the investigation to confirm or negate the positive result of the Checkcard screening. The Checkcard is being incorporated into the Air Force Safety Center's AF Safety Automated System (AFSAS).

2. Operational Risk Management of Fatigue Effects.[6,7]
This was our first attempt to use SAFTE and well-accepted fatigue countermeasures in the context of operational risk management. We listed the known, primary physiological and psychological effects of fatigue. These effects
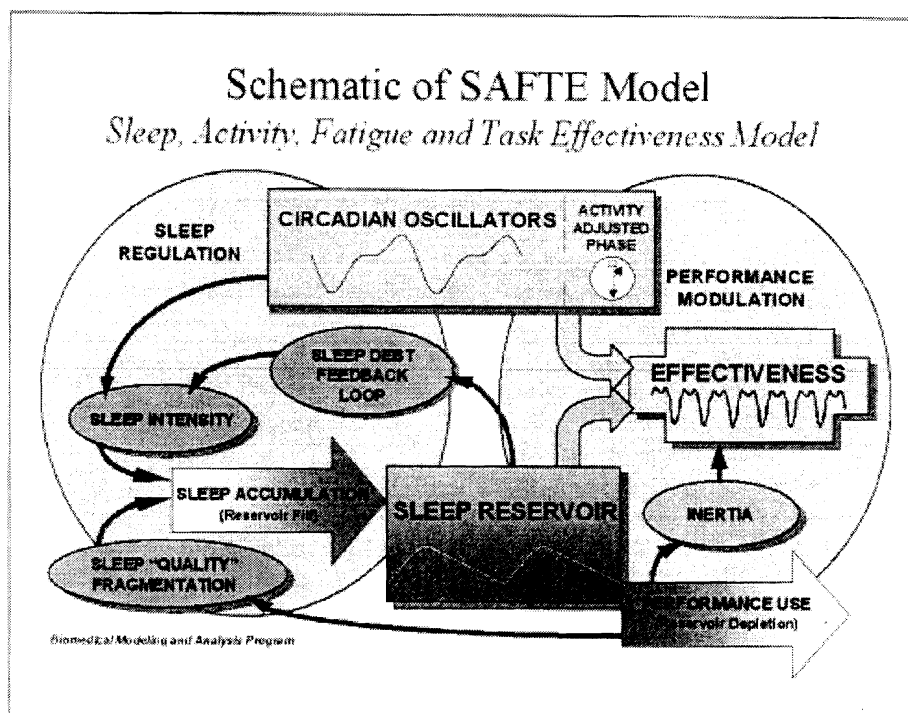

Schematic of SAFTE Model
Sleep, Activity, Fatigue and Task Effectiveness Model

Figure 1

were aligned approximately with the cognitive and physiological tests shown to be sensitive to the fatigued state. The extrapolation of the listed effects to safety-sensitive jobs was explained through examples. Each effect had the potential to cause harm in military operations and, thus, was a hazard. Using SAFTE, we quantified the risks associated with five types of fatigue: physical fatigue, circadian effects, acute fatigue, cumulative fatigue, and chronic fatigue. The best fatigue countermeasure is sleep, which is the only countermeasure that provides recovery. It also reduces the probability that fatigue will have an effect on mission safety and, concomitantly, reduces the exposure to fatigue. When adequate sleep cannot be used to counter fatigue, then one must consider the use of "Go" and "No-go" adjuncts, including schedule adjustments and pharmacological adjuncts. These adjuncts serve to reduce the severity of fatigue effects or the exposure to fatigue-related risk. All controls except sleep should be viewed as "band-aid" approaches, to be used as a last resort when other controls are insufficient and the mission must be accomplished. Recovery sleep will still be necessary after the other controls have been applied to accomplish the mission.

3. Scheduling Aircrews I: Intra-Theater 24/7 Operations.[8]
Aircrew fatigue problems had been documented in 24/7, intra-theater, tactical airlift operations. One reason was the irregularity of the schedule for a given crew across days.

There are three approaches to 24/7 scheduling: 1) fixed shifts; 2) rapidly rotating shifts; and, 3) slowly rotating shifts. We assumed that some sort of a rotating shift was necessary, and applied seven scheduling principles:

1. Set a normal, *maximum* crew duty period (CDP) of 14 hours to allow a crew to work on a 24-hour cycle.
2. Follow each CDP longer than 14 hours with a day off.
3. Schedule either
   - A long sequence of night shifts in a slowly-rotating schedule (with adequate sleep facilities) to allow acclimation to night work and day sleep, or
   - A minimum number of consecutive night shifts in a rapidly-rotating schedule to minimize exposure to night work where sleeping facilities are inadequate.
4. In a rapidly-rotating system, follow each night shift with 24 hours off.

(See OWNING THE NIGHT, p. 38)

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5. Schedule long, contiguous periods of time off.
6. Assure equity by giving all aircrews equal demands for long CDPs and night work and equal access to day work and good quality time off.
7. Schedule an aircrew such that their show time does not differ more than one hour on successive days to allow the crew to continue on a 24-hour cycle.

We used five scheduling variables to produce an example of a slowly-rotating schedule and an example of a rapidly-rotating schedule. The variables were:

1. Number of crews and manning ratio.
2. The relative numbers of work and free days.
3. CDP and crew workload.
4. The sequence of work and free days.
5. Show times.

We generated one example of a slowly-rotating schedule for crews with good day-sleep quarters and one example of a rapidly-rotating schedule for crews with poor day-sleep quarters. These examples were assessed for fatigue risk by plotting them in *FAST*™. Schedules such as these provide equity across crews, predictability for a crew, and long, contiguous periods of time off that should help combat the onset of chronic fatigue.

4. Scheduling Aircrews 2: Nighttime Missions.[9] The objective of this effort was to develop SAFTE-based aircrew work-rest guidance that dealt with the shift lag issues associated with nighttime missions, such as scheduling night-vision-goggle (NVG) training sorties. This guidance would be used by operational commanders to determine when best to employ their crews.

We constructed guidance for military aviation training missions by the quarter of the day. Evening missions generally operate within the period 1800-0000, and allow crews to accomplish their night approaches, landings and other required training, such as operations with NVGs, while night missions are flown in the 0000-0600 period. We presented options for flying evening missions, night missions, acclimation to permanent night missions, and re-acclimation to day work.

5. Scheduling Aircrews 3: Deployment.[10] The objective of this effort was to develop SAFTE-based aircrew work-rest guidance that dealt with the jet lag issues associated with deployments across time zones. This guidance would be used by operational commanders to determine when best to deploy their crews. We examined 12 scenarios in *FAST*™: 4.5-, 9- and 12.5-hour changes to both the east and the west with subsequent day or night CDPs. We made recommendations for scheduling practices, including the use of alertness aids and sleep aids.

6. Shiftwork Scheduling. The AF Inspector General and the Air Staff has tasked us to write an Air Force Manual on shiftwork scheduling. The number of possible shiftwork schedules is infinite, but our approach, called principle-based scheduling, constrains the candidates to those schedules that are simple, practical to implement and least harmful to worker health, job performance and attitude. The constraints are nine scheduling principles drawn from our physiological and behavioral research, careful considerations of the zero-sum nature of the clock and calendar for cyclic schedules, and calculations supported by *FAST*™.

This manual is aimed at managers, supervisors, shiftwork schedulers, and employees. It will help them design optimal shiftwork schedules that produce beneficial changes in the workplace. Specifically, they should: 1) understand the nine principles that should be applied to shiftwork scheduling; 2) learn how to use the principles to specify the nine components of shiftwork scheduling; and, 3) understand how to assess the effects of a change in a shiftwork schedule. Workplace scheduling applications based upon recommendations in the manual should minimize fatigue effects in shiftwork.

Summary

The most unpredictable component in any human-machine system is the human. After training and currency, the greatest contributor to that human variability is fatigue. When an operation requires staffing 24/7, sleep quality and quantity will always suffer and human sleepiness and fatigue will always occur. Fortunately, the biological changes and rhythms that cause fatigue-induced variability in human performance are relatively lawful and predictable. We have used the DoD's Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model, as implemented in the *FAST*™ software, to support five quantitative assessments. Finally, we have been tasked by the AF Inspector General and by the Air Staff to write an Air Force Manual on shiftwork scheduling.

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solution, if one existed in that direction (see Figure 2). All he had to do was build an algorithm to land in a region in which $F(N)>N$ and he would get a new solution. A little more thought convinced him that the number of solutions was bounded.

In short time, the Lieutenant programmed the algorithm, tested it, and showed it to the Major and the Captain. It was clear they didn't completely understand — or believe — his explanation of the $F(N)$ calculation and search technique. "Awfully long, isn't it?" the Captain asked. "Are you sure you can't find a simpler way to solve the problem? My program wasn't more than fifteen lines. Your run time must be horrendous."

"Well, I could probably shorten it some, but I was trying to program a more general case, not just find the smallest solution. And no, it runs fast. Go ahead and try it."

"So what are all these numbers it's spitting out?" The Captain pressed, trying not to be condescending. "Where's the solution?"

"These are all solutions to $F(N) = N$. This first one is the smallest one. Here, the program's about to stop. See, there's the last solution: 1,111,111,110. And it only took 40 seconds."

The Captain made a quick alteration to his own program and ran it. "Sure enough, here are some of the other numbers you got. But my program has stopped at
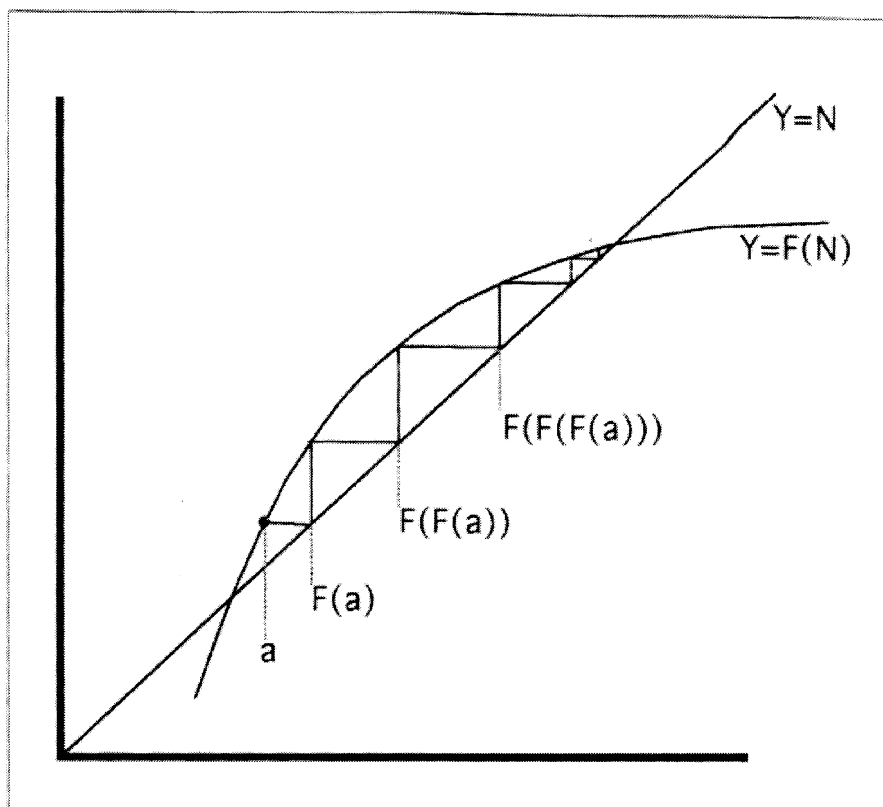

Figure 2. Graphical interpretation of the search sequence a, F(a), F(F(a)), ... for a region above the Y=N line. The sequence can be proved to always end at a solution of F(N)=N, if one exists that is larger than a.

2,600,001."

The Lieutenant glanced over. "No it hasn't. It's just that the next solution will take five times as long as the last, which took ten minutes. And it gets worse. To get all the solutions, you'd need to run three days.

"But what about the original problem?" the Major pressed. "Maybe your program's faster if you're trying to get all the solutions, but how long did it take to find the first solution?"

"Somewhere around 150 milliseconds. So it's much faster for both goals. But you raise a good question. There are lots of tradeoffs involved here. Do we need to get the first answer or all of them? Do we need to minimize the run time or the programming time? Are there memory and time tradeoffs — for example, is it faster to store all the previous solutions in case you need them again, or should you just recalculate?"

The Major was intrigued. "This is all new to me. I've used that problem for

years, and no one's ever come up with a different algorithm - just a few programming tricks."

Leaving the Captain staring at the code listing and mumbling something about hardwiring answers, the Lieutenant and the Major left to talk a bit more seriously about how the shop might use operations research.

Editors Note

Colonel(s) **Peter Vanden Bosch**, USAF, PhD, is Deputy Director, Analysis Integration and Foundations in the newly formed HQ USAF/A9 (Air Force Studies and Analyses, Assessments and Lessons Learned.) This story is almost purely nonfictional; it occurred in the 1980s in a research lab. No engineers were harmed in its production. Modified with permission from *Mathematics Teacher*, copyright 1997 by the National Council of Teachers of Mathematics. All rights reserved. ○